CAE METHODS FOR SIMULATING FMVSS 201 INTERIOR HEAD IMPACT TESTS

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ABSTRACT

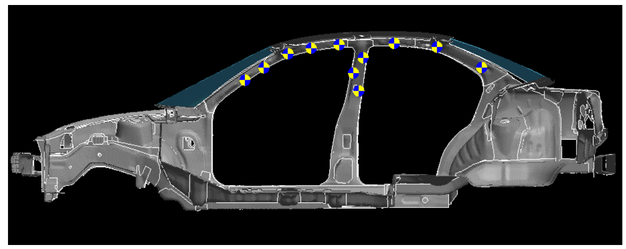
This paper describes progress in CAE techniques for the simulation of interior head impact (IHI) tests to FMVSS 201. Validation of the FT-Arup Free Motion Headform finite element model as a predictive tool for IHI is shown. Details of modelling the behaviour of plastic trim under impact conditions are included, and an efficient method of setting up the many load cases is described. Results are compared with test, showing the importance of the level of detail in the models. Finally, some models are presented that illustrate the effect of using the same Body-in-White for multiple tests at the same impact point, which is a common testing procedure.

INTRODUCTION

The test procedure FMVSS 201 [1] was established to increase protection from head injury in crashes. Depending on the vehicle type, e.g. the number of pillars, there are up to 23 target points to consider. In addition to the points covering the A, B-C and D pillars and side rails (Figure 1), the tester is at liberty to choose any hard point, such as a seatbelt anchor or grab handle. For each point the worst impact angle must be found within a given range, requiring tests at a minimum of 3 angles in the horizontal plane.

The head injury criterion, HIC(d), is calculated as a function of the headform acceleration and must be under 1000 to pass the test. The HIC(d) result depends on trim design, i.e. surface shape, rib configuration, crush space under the trim, and also on body stiffness. If the trim design is changed to improve results for one impact case, it is possible for results to worsen in other neighbouring impact cases. Further, there are strong pressures from packaging and styling to minimise the space occupied by the trim. This requirement conflicts with the need to absorb energy.

To optimise a trim system by testing alone is clearly impractical; CAE techniques are increasingly relied on. This paper describes the CAE techniques and highlights issues such as materials modelling, which for typical trim materials is not fully developed, and demonstrates the extent of the Body in White that should be included. Methods of setting up the models are presented together with typical correlation to test. Results are presented that quantify the effect of using the same body structure for multiple trim tests.



.**Figure 1 Impact points for IHI on a typical BIW.**

THE FREE MOTION HEADFORM MODEL

Validation and Correlation

The free motion headform (FMH) used in the FMVSS 201 tests is shown in Figure 2. A finite element model of the FMH (Figure 3) was developed and validated by First Technology Safety Systems inc under the FT-Arup alliance. Calibration was performed by dropping the headform from 250, 375 and 500mm onto a rigid surface. The acceleration of the FMH in the model and in test are compared in Figure 4. A further validation test has been performed by impacting the headform at 15mph onto a deformable closed steel box section, which is more representative of the application and also shows good correlation (Figure 5). The model is run in LS-DYNA [2].

Figure 2 The free motion headform (courtesy of Millbrook Proving ground Ltd).

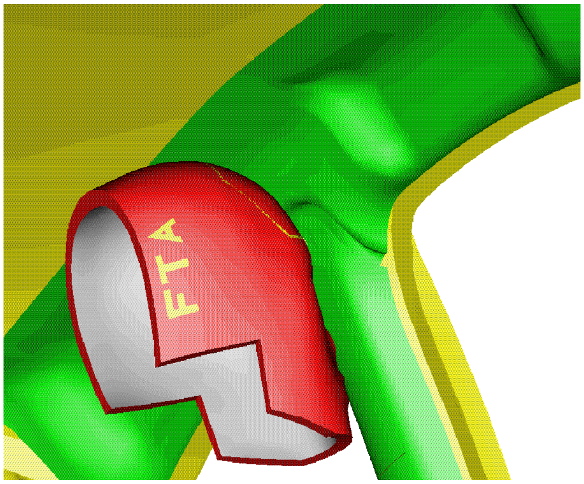


Figure 3 The FT-Arup free motion headform.

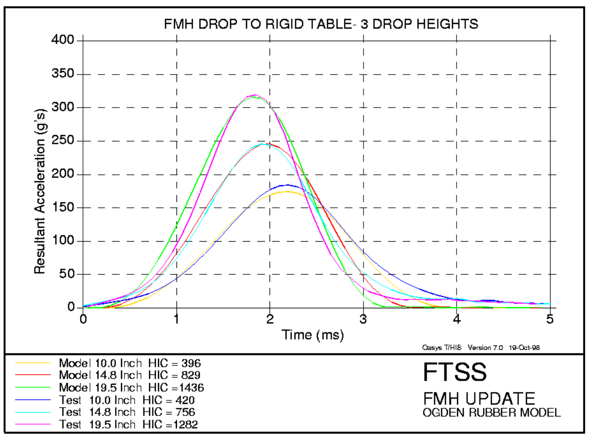


Figure 4 Drop test onto a rigid table.

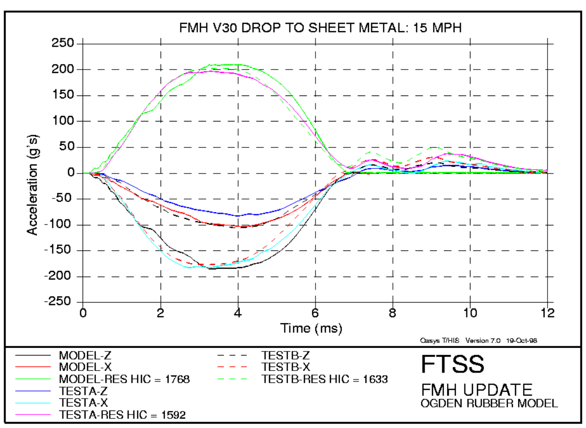


Figure 5 15mph impact onto a steel box section.

SETTING UP FE MODELS

The models are set up using Oasys Primer [3]. A database of target points is set up, which includes the maximum and minimum horizontal and vertical angles for each point. The head is positioned by selecting the desired target point and horizontal angle, then dragging to achieve the vertical angle. The software automatically sets up the contact to the trim and initial velocity conditions. Accidental penetration of the head into the trim, which will give spurious results, is prevented by a penetration checker. Setting up a model in this way takes less than 5 minutes. Thus the large number of finite element models needed to analyse the different impact points and angles can quickly be set up. For subsequent design changes, the software enables easy repositioning of the headform.

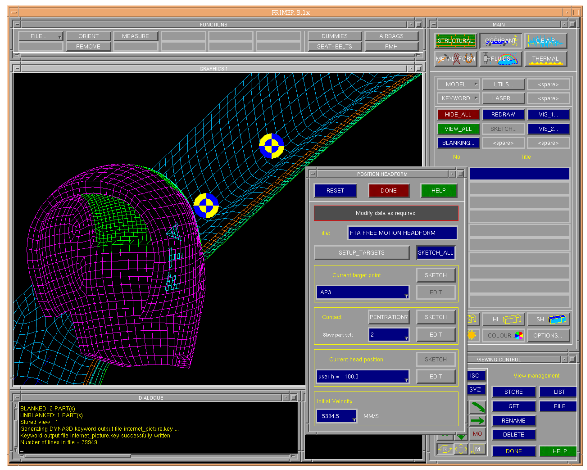


Figure 6 Oasys Primer used for setting up model.

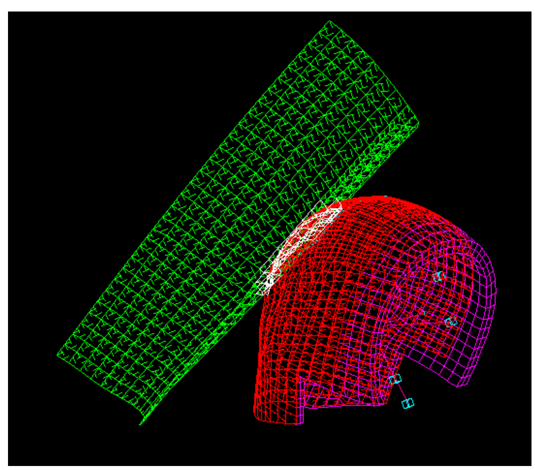


Figure 7 Penetrations are highlighted in white.

FE MODELLING TECHNIQUES FOR IHI

The Interior Trim

A typical plastic trim (figure 8) consists of a curved surface or substrate with integrally moulded housings for clips which attach to the body in white. Higher HIC(d) values are often obtained when the impact is in the region of the clip housings. Retaining clips may break if impacted at angles that load them in shear. The trim is usually reinforced with ribs, which may be integral or part of a fitted rib pack, to help absorb energy. They do this by deforming and crushing or breaking under the impact of the head.

It is, therefore, necessary to model as accurately as possible, the geometry and material behaviour of the rib structure and clip housings. This is achieved by using a very fine mesh on critical parts (elements of 2-4mm are typical) and ensuring that three rows of elements are used through the depth of the rib to allow buckling (see figure 9). The draft angle of moulded ribs (typically 1 degree) may also be taken into account by varying the thickness of each row. A tied contact may be used to constrain the ribs to the substrate and simplifies the meshing of the model. Fully integrated shell elements with 5 through thickness integration points have been shown to model the modes of deformation with more accuracy.
The clips themselves should be modelled as beam elements which allow independent definition of tensile and shear characteristics, but the clip housings are modelled in detail using shell elements.

Modelling of the material properties of plastics is problematic due to the lack of experimental data. Effects that should ideally be represented include:

- Asymmetric yield surface, with lower yield stress in tension than compression. This is thought to be due to a voiding mechanism that occurs under tensile loading. Data derived solely from tensile tests is misleading, particularly where the principal loading is compressive such as in the ribs under the impact point.
- Strain rate sensitive yield stress
- Strain rate sensitive ductility (generally less ductile at high strain rates)
- Strain rate sensitive stiffness and viscoelasticity
- Anisotropy related to flow direction during mould filling
- Effect of cooling rate on mechanical properties

Unfortunately, neither the commonly available experimental data nor existing material models in finite element codes support such a detailed approach. Typically, a series of tensile tests is undertaken at different strain rates, and the yield surface is assumed to be symmetric, leading to loss of accuracy of the predictions. A new theoretical model and test procedure currently under development [4,5] treats the voiding mechanism explicitly to account for the different tensile and compressive responses, and will form the basis of an enhanced material model for LS-DYNA in the future.

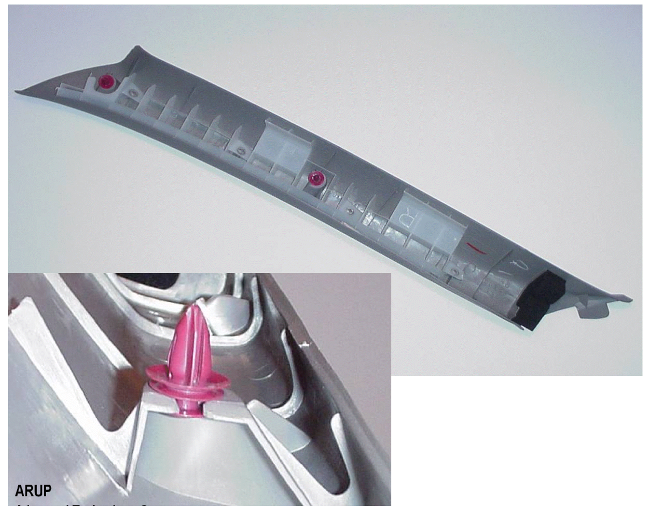


Figure 8. A typical A-pillar trim showing the clip housing.

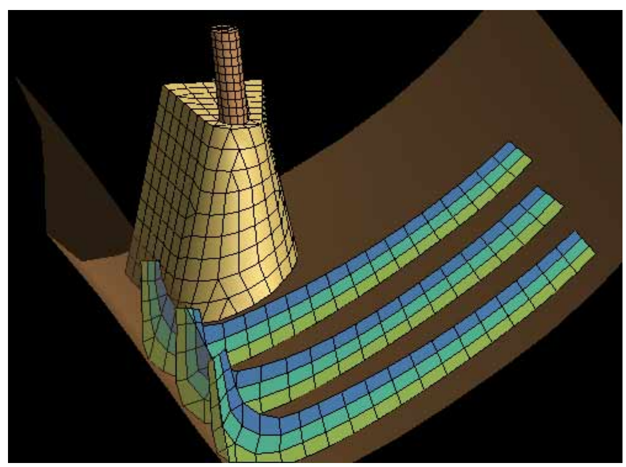


Figure 9 CAE model of trim with ribs and housing.

The Body in White Structure

The IHI tests are performed on a complete trimmed vehicle body, supported at the suspension points on effectively rigid mounts. The truest boundary conditions and therefore the most accurate results are obtained by modelling the entire vehicle body (figure 10) with a refined mesh in the areas of interest. This however requires long computing time (around 12 hours on a typical workstation) and is only appropriate when a close correlation to test is required.

Investigation of a new design may safely be done using a cut down half body (see figure 11) with appropriate boundary conditions. This reduces computing time to 6 hours but changes the HIC(d) by –5% to +15% compared with the full body model at the different impact points (see example in Figure 13). This variation is within the typical experimental scatter and is considered acceptable.

For design iterations, e.g. the comparison of different rib structures within the trim, a fully cut down model is the most appropriate (figure 12). This may consist of just a single pillar restrained at the cut ends. The computing time is reduced to about 1 hour but the HIC(d) differs from the full model by up to 40%. To predict the HIC(d) and optimise the final design, the model must be rerun with the half body.

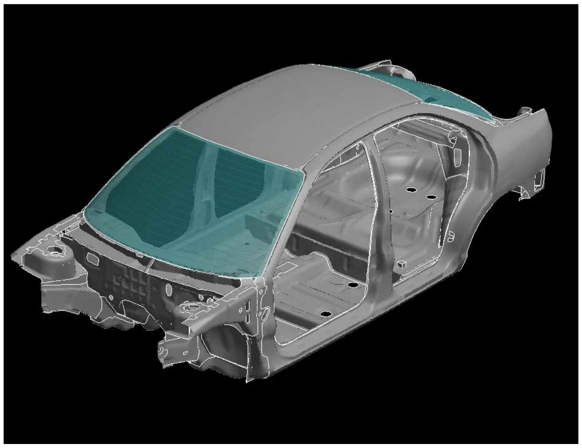


Figure 10 The complete vehicle body.

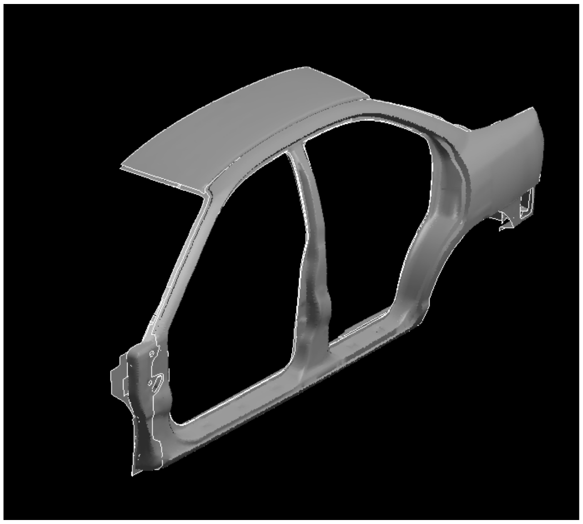


Figure 11 The half vehicle body.

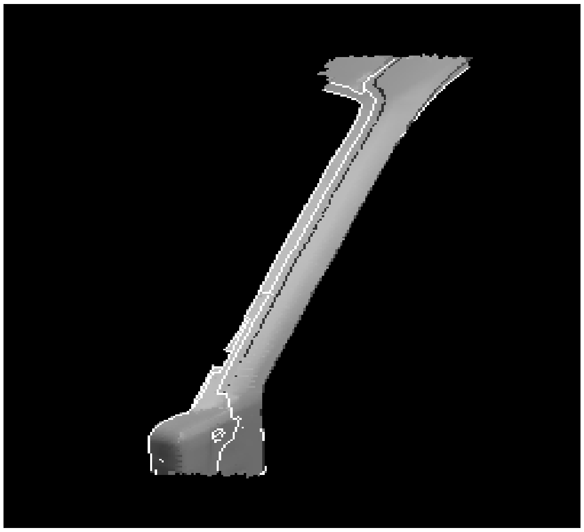


Figure 12 The fully cut down model.

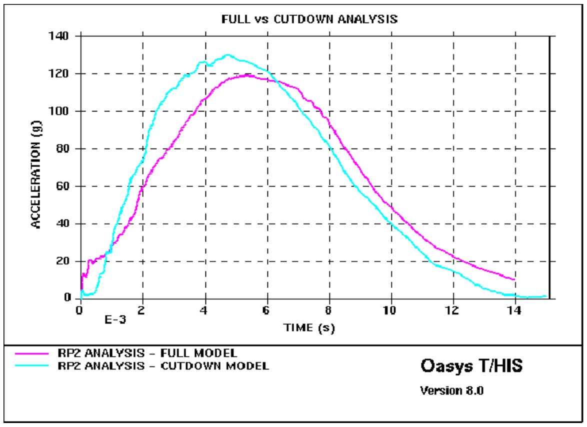


Figure 13 D-pillar head accelerations compared.

Correlation to Test

Confidence in CAE as a viable method for predicting the results of IHI tests is developed by correlating the response of the model to test. It is important not only that the HIC(d) is predicted reasonably accurately but also that the curves show the same features. As a general observation, the early part of the pulse will be dominated by the behaviour of the trim and the fixings, whereas the latter part will be affected by the body stiffness as the trim bottoms out. A typical result is shown in Figure 14. A good model should predict HIC(d) within the test-to-test scatter, about 10-20%. The analysis shown in Figure 14 predicts HIC(d) to within 1% but such close correlation is fortuitous and should not be expected in general.

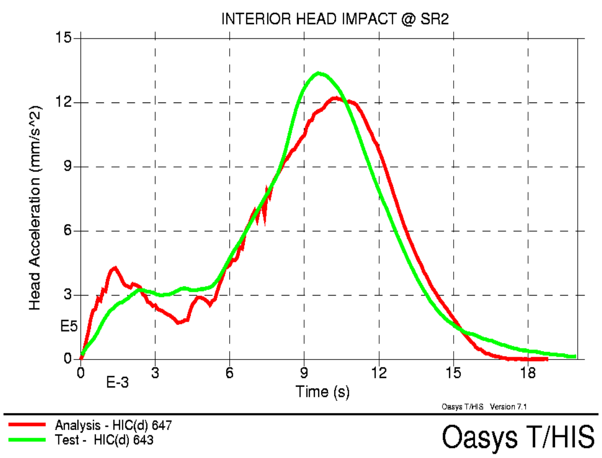


Figure 14 IHI correlation to test.

CAE INVESTIGATION OF TESTING METHODS

A new trim is fitted for every test, but for practical and economic reasons the same vehicle body is used for a whole series of tests. It is thought that this practice might contribute to the wide scatter of test results reported. If the first test causes plastic deformation of the body, one would expect the result of subsequent tests to be affected by the work hardening that occurred during the first test and by the change of geometry leading to a change of stiffness. To investigate this effect, a model was run twice. The first run was allowed to continue after the impact until the stresses had relaxed to a steady state. Then the deformed geometry, work hardening and residual stresses were used as initial conditions in the second impact, for the body structure only.

To demonstrate the principle, impact on an umtrimmed A-pillar was modelled. After the first impact the maximum plastic strain was 8% and the A-pillar was noticeably deformed (Figure 15). In the subsequent impact the HIC(d) increased by 29% (see Figure 16). The procedure was then repeated with the addition of a simple ribbed plastic trim on the A-pillar. The maximum plastic strain in the body structure after the first impact was then less than 3% (Figure 17) and the HIC(d) in the second impact increased by 7% (Figure 18). The study suggests that, even for trimmed bodies, the test method could contribute to the scatter of results. It is, however, no more significant than other factors, such as test equipment alignment or variations in trim fit from vehicle to vehicle.

Table 1. Effect on HIC(d) of multiple impacts on the same body structure.

	First impact	Second impact
Without trim	779	1002 (+29%)
With trim	540	577 (+7%)

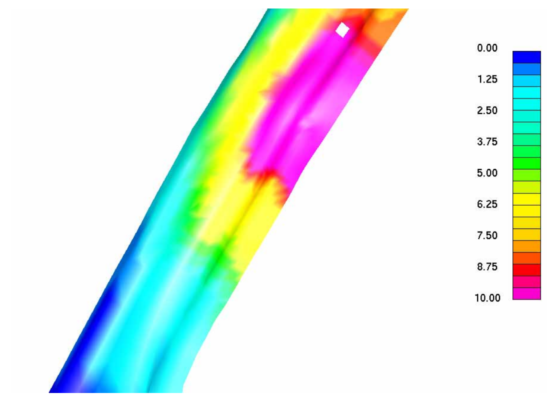


Figure 15 Untrimmed A pillar after first impact.

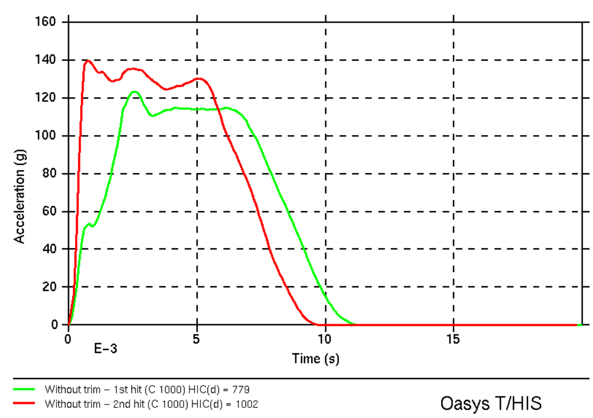


Figure 16 Two impacts with untrimmed A-pillar.

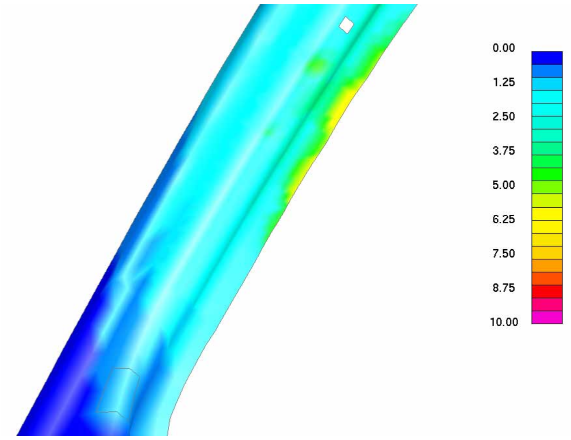


Figure 17 Trimmed A-pillar after first impactar.

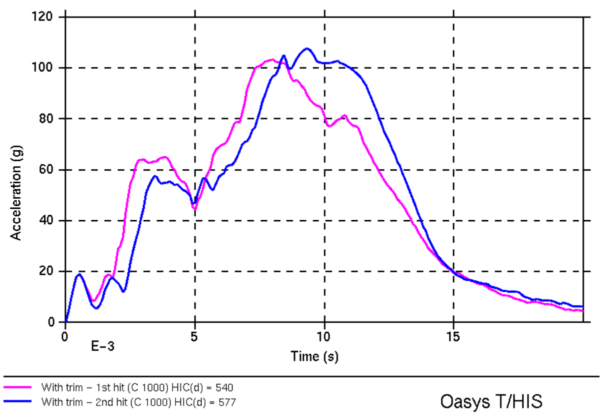


Figure 18 Two impacts with trimmed A-pillar

CONCLUSIONS

- The FT-Arup Free Motion Headform is validated and gives good correlation to test
- Trim modelling techniques are well understood but material modelling must be developed further, in particular with respect to the asymmetry of the yield surface due to voiding.
- To develop trim design by testing only is not possible, as too many tests would be needed.
- CAE can be used to improve trim design to pass the tests
- CAE can also be used to study different test techniques, with a view to saving money in testing. The use of the same body structure for multiple tests has been shown not to lead to excessive variability of results

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